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Effect of inspection errors and preventive maintenance on a two-stage production inventory system

M.A. Darwish*, M. Ben-Daya

Systems Engineering Department, King Fahd University of Petroleum and Minerals, Dhahran, 31261, Saudi Arabia

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Abstract

The effect of imperfect production processes on lot-sizing decisions has received a lot of attention in the literature. These efforts have mostly been confined to single-stage production systems. The issue of imperfect production processes has not been adequately addressed in the context of multistage production/inventory systems. In this paper, we propose a production inventory model that takes into account the effect of imperfect production processes, preventive maintenance and inspection errors. Numerical examples are presented for illustrative purposes.

Keywords: Multistage systems; Lot sizing; Imperfect processes; Inspection errors; Preventive maintenance

1. Introduction

In the real-world industrial settings, products are processed through multi-stage production systems, where raw material is transformed into the final product in a series of processing stages. Although several manufacturing stages are required in many industries (i.e., plastic industry, food processing, and machine industry), increasing automation in manufacturing processes has reduced the number of operations required for simple products and parts of complex products. Two-stage production systems can be found in many applications, for example processing and packaging food, extruding and milling plastics, shearing and punching or rolling and cutting metals Szendrovits (1983). In addition to representing many real-life applications, two-stage models can also be used to approximate more complex multi-stage systems.

Two-stage production systems gained considerable attention in the literature. Szendrovits (1983) proposed several two-stage production/inventory models in which smaller lots are produced at one stage and one larger lot is produced at the other stage. Kim (1999) carried out thorough analysis of the two-stage lot-sizing problem where the production rates are finite at both stages. He divided the problem into different cases. Moreover, he presented an optimal solution procedure for each case. Recently, Hill (2000) offered an alternative way to derive and present similar results. His presentation is more intuitive and concise. Moreover, he allowed the batch sizes at given stage to differ. In addition, his policies give minimum inventory of the finished product.

*Corresponding author. Fax: +96638604426.
E-mail addresses: mdawish@ccse.kfupm.edu.sa (M.A. Darwish), bendaya@ccse.kfupm.edu.sa (M. Ben-Daya).

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In the above models, it is assumed that the quality of the items produced is perfect. In general, the quality of product depends on the state of the process. Rosenblatt and Lee (1986), Lee and Rosenblatt (1989), Porteus (1986), Hariga and Ben-Daya (1998), among others, investigated the quality aspect for single-stage production systems. Ben-Daya et al. (2003) proposed imperfect production model with inspection errors. They extended Szendrovits (1983) model by considering the effect of imperfect production processes, inspection errors and preventive maintenance (PM) on lot-sizing decisions. The model calls for PM or restoration with each inspection. Moreover, the reduction in the age of the process after each PM is considered to be constant.

In this paper, we consider production/inventory model for imperfect production processes that incorporates inspection errors and PM. This model is different from the model developed by Ben-Daya et al. (2003) in several aspects. First, we follow Hill's presentation Hill (2000) which keeps the inventory of the finished items as low as possible while minimizing the expected total cost. Second, PM is not necessarily performed with each inspection. Although PM is performed at the time of the inspection, its frequency is a decision variable. Finally, each PM reduces the age of the process by factor which is proportional to the level of PM performed, in other words, more reduction in the age of the process requires higher PM cost.

This paper is organized as follows. The assumptions and necessary notation are described in the next section. In Section 3, the proposed model is presented. A hybrid Hooke and Jeeves–Tabu search solution procedure is presented in Section 4. In Section 5, a sensitivity analysis with respect to key model parameters is conducted. Finally, Section 6 concludes the paper.

2. Problem definition and assumptions

For convenience we shall follow most of the definitions and assumptions in Ben-Daya et al. (2003) which we state here so that this paper is self-contained. A single end product manufactured by two-stage production system, for an infinite time horizon, is considered. At the first production stage (stage 2) raw material is processed at a finite rate, in batches, to produce an intermediate product which is inspected as produced. Non-conforming intermediate items are discarded at the end of the production run and conforming items are transferred to stage 1 where they undergo further processing at a finite rate to produce end products. Finished items are inspected, non-conforming items are discarded and conforming ones are used to continuously satisfy a constant and deterministic demand. This system is depicted in Fig. 1.

We assume that the production rates at each stage exceed the demand rate. Moreover, the production rate at stage 2 exceeds the production rate at stage 1, that is $P_2 > P_1 > D$, where P_1, P_2 and D are production rates at stages 1 and 2 and demand rate, respectively. This assumption ensures that no stage starves because of lack of input from the previous stage. This is in line with common industrial practice. In addition, the lot size produced at stage 2 is assumed to be more than that at stage 1. This is the case, for examples when parts made in the initial stage are assembled in the second stage.

Two types of inspection are conducted, product inspection and process inspection. Product inspection is error prone, this implies that conforming items may be rejected (type I error) and non-conforming items may be accepted (type II error). The production processes at both stages are assumed to be in control at the start of each production run. They may shift to an out of control state and start producing fixed fraction of non-conforming items at random points in time. A general probability density function is used to describe the time to failure at stages 1 and 2. However, the process inspection policy is as follows. For stage 1, the process is not inspected during a production run. If it shifts to the out of control state, it remains in that state until the next setup. Also, perfect inspection of the process at stage 2 is performed to assess the status of the process. If the process is found to be out of control, it is restored to the in control state with no effect on the age of the system. Process restoration incurs an additional cost which depends on the duration of the out of control state. The number of inspections during each production run is considered to be a decision variable.

The process at stage 2 undergoes scheduled PM at a subset of the inspection epochs depending on the

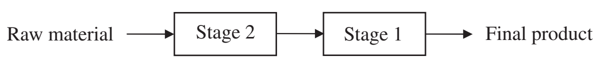

Fig. 1. Two-stage production system.